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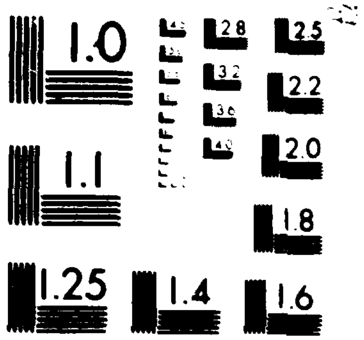
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REPORT SD-TR-86-99

On-Orbit Observations of Single Event Upset in Harris HM-6508 1K RAMs

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This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The SEU and latchup rate of a satellite subsystem containing 384 Harris HM-6508 RAMs was observed over a 2 year period. A total of 47 single SEUs, 9 double, 1 triple and 1 quadruple events were observed; the multiple events were 19% of the total. No latchup was observed. The error rate was 7.6×10^{-2} SEUs/chip-year and an upper limit was found of the ratio of latchups/SEUs of 1.7×10^{-2}. The observed SEU rate was consistent with predictions based upon laboratory tests, using the Lawrence Berkeley Laboratory 88" cyclotron.

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PREFACE

The authors would like to thank Drs. W. A. Kolasinski and R. Koga for many discussions concerning SEU test results, Drs. D. L. Chenette and W. F. Dietrick for their galactic cosmic-ray data, and Dr. J. Adams for a copy of his computer program for generating upset rates from test data.

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FIGURES

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Introduction

Single event upset (SEU) due to single charged particles in spacecraft microelectronics has grown as a subject of interest in the last several years from a curiosity, often eliciting disbelief, to a subject of vital interest. Binder et al.* published the first analysis. The importance of understanding the vulnerability of various microelectronic components to SEU has resulted in a substantial effort in ground testing using various particle accelerators, and the in-flight error rate estimated from the test results. The IEEE Transactions on Nuclear Science regularly contain detailed descriptions of laboratory test and analysis. However few correlations of extensive flight data with estimates from ground testing have been published, in particular where detailed testing of the parts with the same pedigrees as those used in the spacecraft preceeded launch. In this paper we give the results of two years of flight observation of a subsystem consisting of Harris HM-6508 1K RAMs, and compare the observations of SEUs and absence of latchup with estimates based upon ground testing with the Lawrence Berkeley Laboratory 88" cyclotron. The purpose is to describe the present state-of-the-art to the non-specialist.

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*Binder, D., Smith, E. C. and Holman, A. B., "Satellite Anomalies from Galactic Cosmic Rays," IEEE Trans. Nucl. Sciences, Vol. NS-22, No. 6, Dec. 2975, pp. 2675-2680.

Description of Observations

The Harris HM-6508 1K x 1 RAMs are part of a subsystem of a satellite in a low, polar orbit. The memory module, used in the subsystem containing the RAMs, consists of three printed circuit cards, with each card containing eight 2K byte memory hybrids, for a total of 48K bytes. Each memory hybrid contains 16 HM-6508 RAM chips. On a regular basis all but 256 bytes of the 48K bytes are examined for bit errors. Two different techniques were used for detecting bit errors. The first technique, a memory check sum, was capable of automatically detecting all single bit and some double bit errors which occurred within a page of memory. A memory page consists of 256 bytes. Memory check sum tests are performed approximately every 90 minutes. To detect a multiple error or to determine the exact location of the bit error within the page the entire contents of the memory is dumped and compared to the load file. Memory dumps are normally performed once a month, or immediately after the check sum routine detects an error. Once the exact location of the error is found, the correct value is reloaded into memory. After the memory is reloaded, the contents of the memory location in question is verified in order to determine if the error was a soft error generated by an SEU or a hard error generated by a part failure or cosmic-ray induced latchup. The data presented in this paper were acquired in the two year period from 1 January 1983 through 31 December 1984.

Results

A total of 72 SEUs were observed during 731 days (2 years) of flight. Several were multiple events; the multiplicity distribution is given in Table 1. It can be seen there have been a substantial number of multiple events, 19%.

Table 1. SEU Multiplicity Distribution

Number of Events	Errors per Event
47	1
9	2
1	3
1	4

The reader may recall from the subsystem description that the memory contents verified only once every 90 minutes, and wonder if the multiple SEUs are not just two independent events that occurred between verifications. First the probability of two independent events between verifications is very small. The total number of SEU events, assuming multiple events are due to a single cosmic ray, is 58. Therefore the error rate is $58/731 = 7.9 \times 10^{-2}$ SEUs/day, or 12.6 days/SEU. Assuming Poisson statistics, the probability that two independent errors occur during the same day, and during the period between verifications is P(same day) $= 2.9 \times 10^{-3}$ and P(between verifications) $= 1.4 \times 10^{-5}$, respectively.

The result for one day implies two events in a single day about once a year. Our two year data set has one such occurrence. Two independent events inside of a single verification period is expected about once per 13 years. We observed 11 multiple events in the two years of observations and thus they cannot, in general, be independent events occurring in a single verification period. Furthermore, the location of the multiple errors gives additional and compelling evidence that the multiple hits are due to a single cosmic ray. Knowledge as to the location of multiple hits also is of great interest in understanding how to minimize deleterious effects from multiple hits. Recall that the HM-6508 RAMs are packaged on 3 circuit cards, 8 hybrids to a circuit card and 16 RAMs to a hybrid. Table 2 is a listing of the multiple events giving some of the location details. In the first case in Table 2 the identity of the RAMs affected was lost.

Table 2. Multiple Hit Numbers

Bits Flipped	RAMs Affected	Hybrids Affected	Board Affected
2	[illegible]	1	1
2	2	2	1
2	1	1	1
2	1	1	1
[illegible]	2	1	1
2	2	1	1
[illegible]	[illegible]	1	1
[illegible]	[illegible]	1	1
2	1	1	1
[illegible]	[illegible]	1	1
2	[illegible]	2	1

Figures 1a, 1b, 1c and 2a, 2b, 2c show bit maps of HM-6508 RAMs for the six cases in Table 2 where only 1 RAM was affected, The location of the affected bits is marked with a filled circle. Note that in the 2-error cases the bits were adjacent, and in the 4-error case lay essentially on a straight line as would be most likely if caused by a single cosmic ray. Needless to say, the probability of this ordering being statistical in nature is truly nil. Unfortunately we do not have information on the hybrid layout and

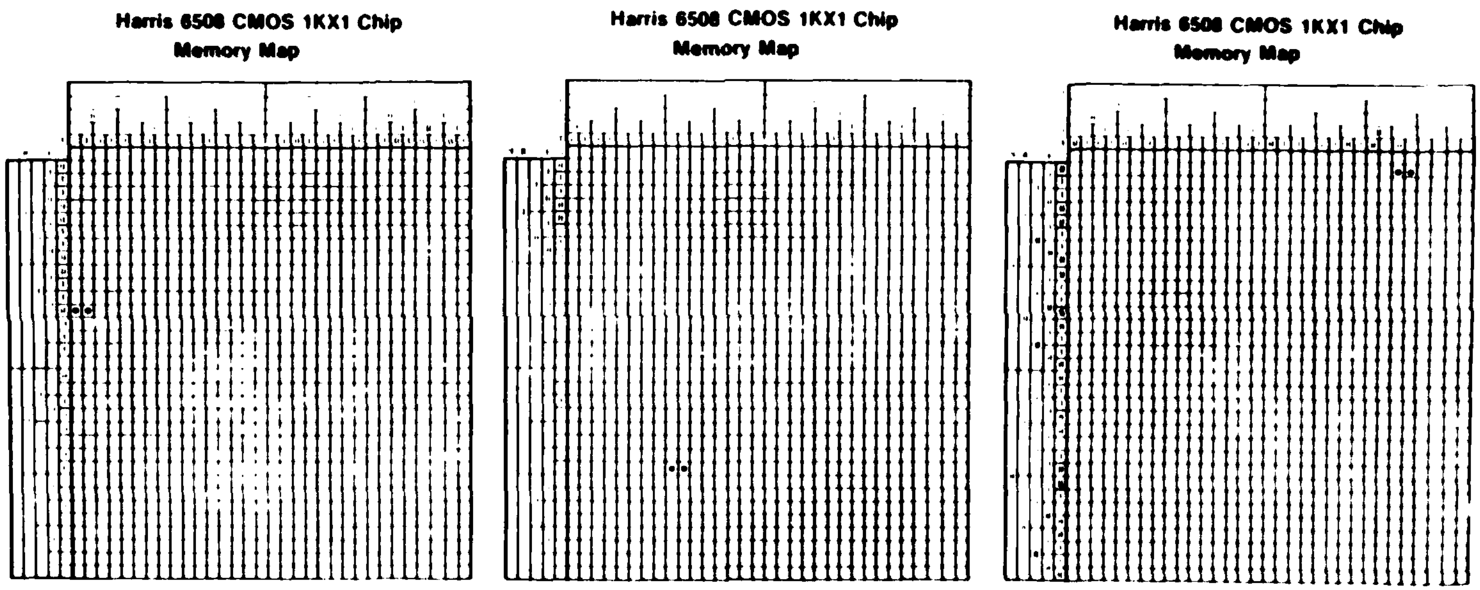


Figure 1. Harris HM-6058 Bit Maps Are Shown for Three Cases of a Double Error. The locations of the errors are shown as filled circles.

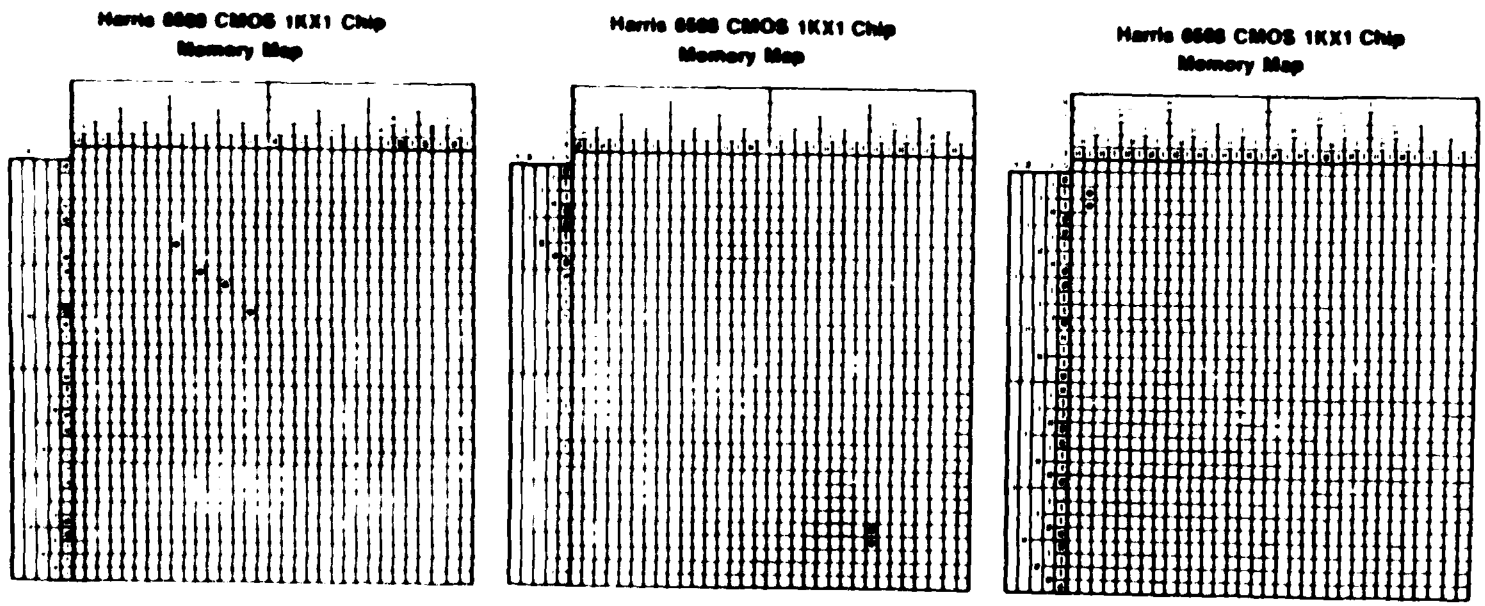


Figure 2. Harris HM-6508 Bit Maps Are Shown for Two Cases of a Double Error. The locations of the errors are shown as filled circles.

therefore cannot comment on the physical configuration of the error locations when more than one RAM on the same hybrid were involved. We do know that in the 2 cases where 2 hybrids were involved the hybrids were in adjacent locations on the same board.

In the two years of flight no HM-6508 RAM latched up. This observation gives an upper limit for the latchup rate of 1.3×10^{-3} latchups/chip-year. This may be compared with the SEU rate of 7.6×10^{-2} SEUs/chip-year or, if each error of a multiple event is counted separately, 9.4×10^{-2} SEUs/chip-year. Thus the ratio of latchup to SEUs is $\lesssim 1.7 \times 10^{-2}$.

It is well known that the galactic cosmic-ray intensity varies over the solar cycle. Therefore it is of interest to look for a time dependence in the SEU rate. These results are given in Table 3. It can be seen that the data suggest that the cosmic flux may have increased in the second half of 1984. Independent observations of the cosmic ray flux are discussed below.

Table 3. Time Dependence of SEU Rate

Time Period	SEU Number	SEU Rate (upsets/day)
1 Jan - 30 June 83	14	$(7.7 \pm 2.1) \times 10^{-2}$
2 July - 31 Dec 83	12	$(6.5 \pm 1.9) \times 10^{-2}$
1 Jan - 30 June 84	10	$(5.5 \pm 1.7) \times 10^{-2}$
1 July - 31 Dec 84	22	$(12.0 \pm 2.6) \times 10^{-2}$

Discussion

It is of interest to compare the observations with predictions based upon laboratory testing. Figure 3 shows data for SEU and latchup, acquired by us. These data indicate that the critical charge for both latchup and SEU are approximately the same, ~ 0.29 picocoulombs. However the cross sections differ by a factor of the order of 100. The in-flight results, discussed above, give a ratio of greater than 50. The observations and tests are

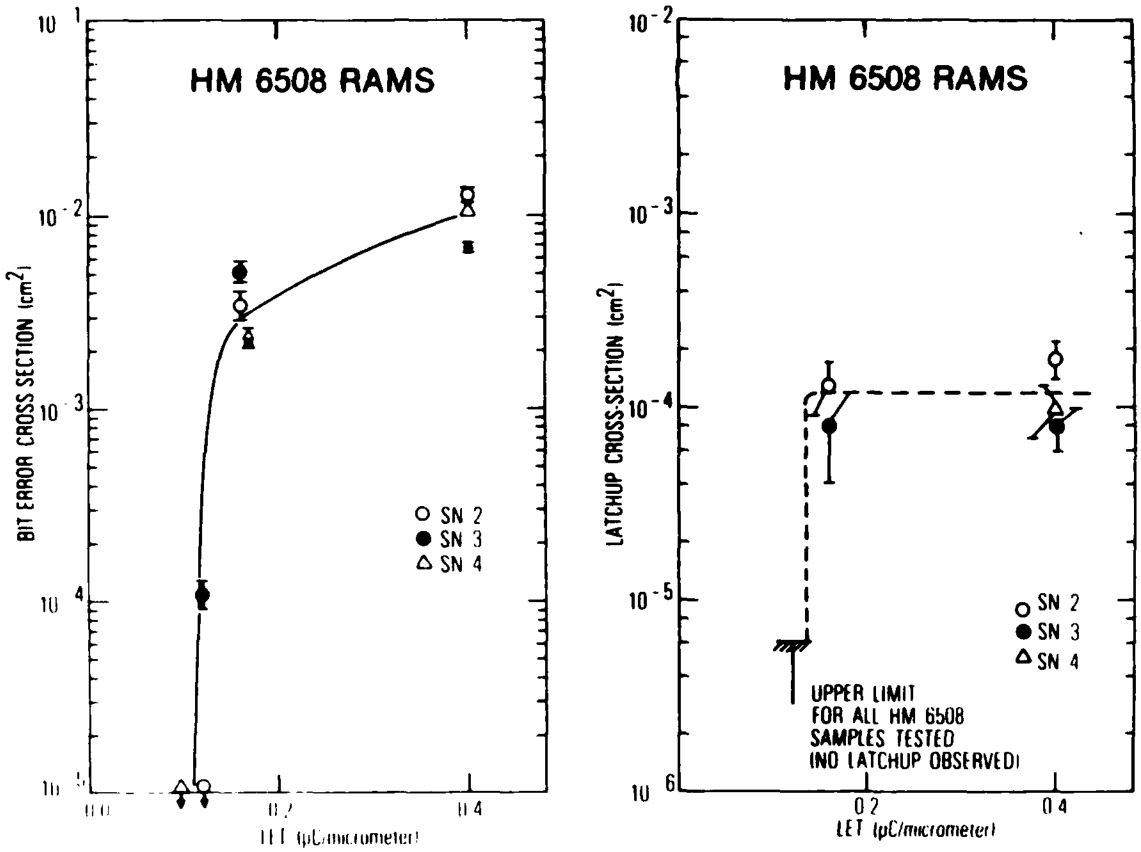


Figure 3. Experimental Data Is Shown of Bit-Error and Latchup Cross Sections as a Function of the LET of the Incident Particle for Three Different HM-6508 RAMs. The three parts are labeled SN2, SN3, and SN4.

consistent but clearly substantially more data are required to arrive at a finite value for the latchup rate.

Figure 4 presents data on the flux of iron nuclei in two energy channels (98.4 - 418 MeV/nucleon and > 418 MeV/nucleon) for the time period from 1973 through 1984. These data are from the University of Chicago experiment aboard the IMP 8 satellite (Chenette,* Chenette and Dietrich.†) It can be seen that the iron flux reached a minimum value during 1981 and 1982 and then started to increase. Note that these data suggest that the SEU rate will increase by a factor of 3 or more over the next few years.

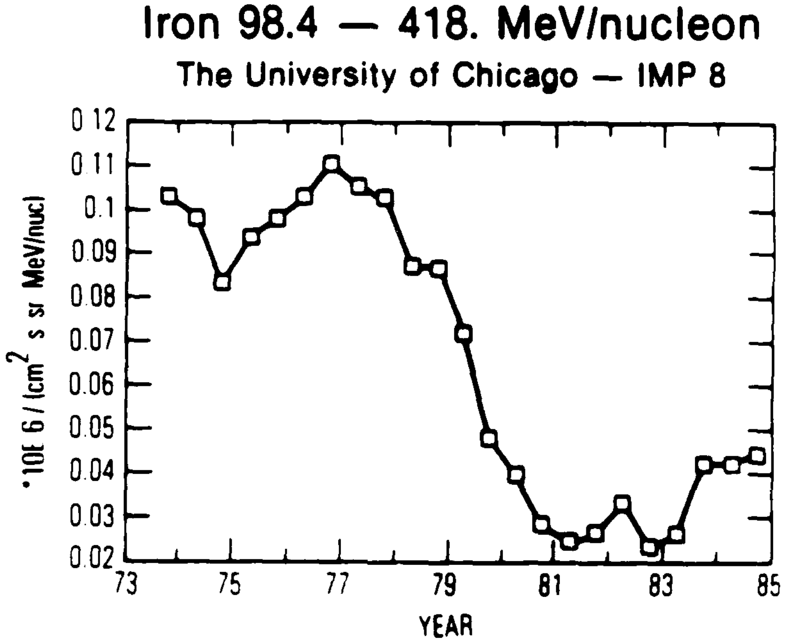
A computer program has been written by Adams‡ which calculates the SEU rate given the measured value of the critical charge and the size of the vulnerable cell in the RAM. The program contains a model of the galactic cosmic-ray flux and its solar cycle modulation, geomagnetic cutoff effects and the finite size of the Earth. This program has been used to compute the expected SEU rate in errors/bit-day.

The HM-6508 parameters used in the calculations were a critical charge of 0.29 picocoulombs taken from the data illustrated in Figure 3. The proper orbital parameters were used and the time in the solar cycle taken as 1984.0, the middle of the period of observation. Figure 5 gives the calculated SEU rate as a function of aluminum shielding thickness. The average SEU rate over the two year period, $(2.07 \pm .27) \times 10^{-7}$, is plotted also as a stippled band. It can be seen that the observed error rate is consonant with a spacecraft shielding of a few grams/cm^2, which is approximately the average value. In fact, it is fair to say that the calculated rate is astonishingly close to the observed SEU rate.

*Chenette, D. L., private communication, 1985.

†Chenette, D. L., and Dietrich, W. F., "The Solar Flare Heavy Ion Environment for Single-Event Upsets: A Summary of Observations over the Last Solar Cycle, 1973-1983."

‡Adams, J. H., Jr., private communication, 1985. See also Adams, J. H., Jr., Silberberg, R., and Tsao, C. H., "Cosmic Ray Effects on Microelectronics, Part I: The New Earth Particle Environment," NRL Memorandum Report 4506, Naval Research Laboratory, Washington, D. C., 1981.



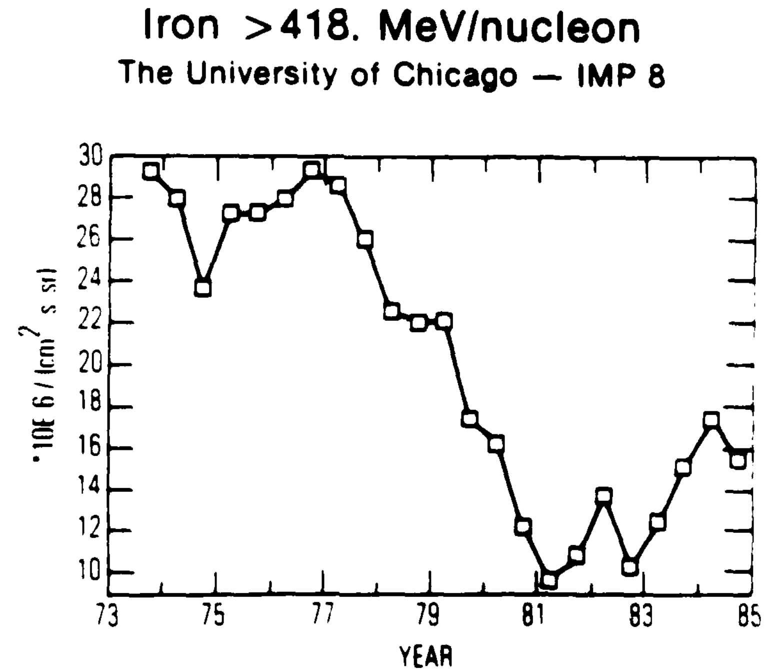


Figure 4. Observations of the Galactic Cosmic-Ray Ion Flux as a Function of Time for the Energy Range from 98.4 to 418 MeV/Nucleon, and for the Energy Range Above 418 MeV/Nucleon.

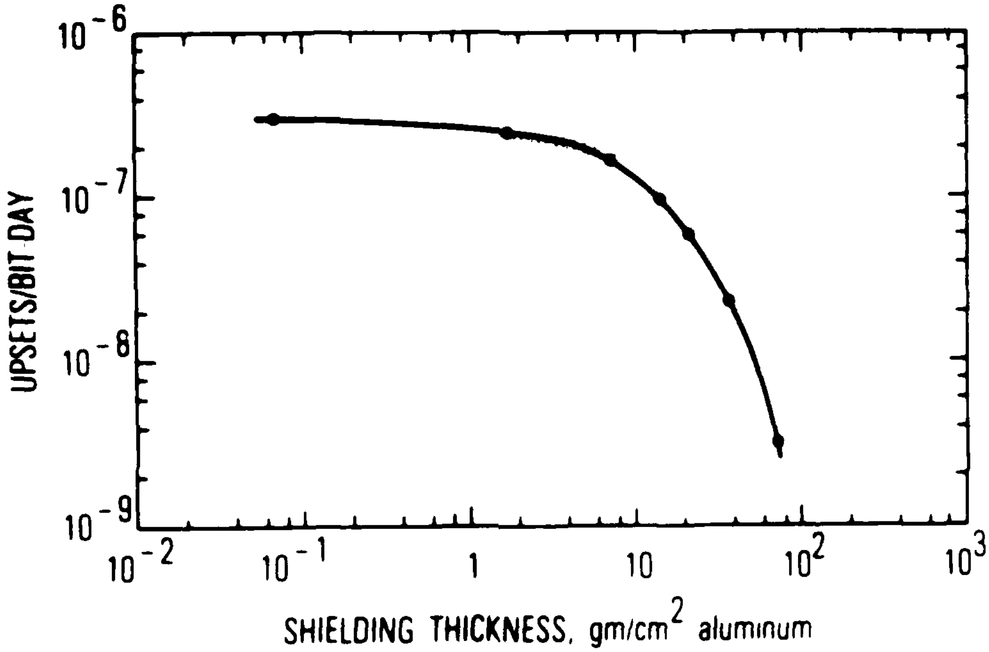


Figure 5. A Plot of the Calculated Upset Rate as a Function of Shielding Using the Laboratory Measured Parameter for the HM-6508. The striped bar denotes the measured, on-orbit rate and its statistical uncertainty.

LABORATORY OPERATIONS

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Materials Sciences Laboratory: Development of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures as well as in space and enemy-induced environments.

Space Sciences Laboratory: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation.

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